

Shallow sub-surface 3D geological models for Environmental and Earth Science Decision Making

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Background

Along with other professions Geological Surveyors need to be good spatial (3D) thinkers although until recently they have been restricted in communicating their understanding of the sub-surface to two dimensional media. Traditionally this has been on paper, and in recent years in Geographical Information Systems (GIS).

At the outset of geological surveying and map-making in 1815 William Smith used a cross-section to illustrate the third dimension of British geology on the classic first geological map. Over time more refined section drawing resulted in outputs such as fence diagrams, ribbon diagrams and block diagrams to show the 3-D structure, while contouring was used to show the nature of individual horizons such as major unconformities or the thickness variations of units or sequences (isopach maps).

In the last 3 decades the advancement in the processing power of computers has enabled scientists to create 3-D models of geological structures. First these were simple meshed surfaces of which perspective views could be obtained whereas today they are solid models of highly complex structural features or entire sedimentary basins. Many of the early developments were pioneered in the hydrocarbon and mining industries resulting in complex proprietary modeling softwares that were operated by a small number of specialists. Now more intuitive affordable software solutions are being rolled out to large numbers of geologists to produce shallow sub-surface geological models for a range of uses. Our organisation the British Geological Survey (BGS) is undergoing this transformation from a mapping to a modeling culture mainly using the Geological Surveying and Investigation in 3D (GSI3D) software tool and methodology as described in this article.

BGS has begun to produce 3-D geological models of the shallow sub-surface (0-200m), the major zone of human interaction, with the initial emphasis on major urban areas and aquifers. These models commonly include detailed information on artificial (man-made) deposits, superficial geology and the upper parts of the bedrock environment.

These models are an essential first step towards a future where geologists will have to develop much more integrated 3-4D modeling of the surface and sub-surface, in partnership with all the other environmental sciences. The geology will form the framework, or backdrop, within which processes and temporal changes are modelled at a series of resolutions.

This is a logical scientific progression and responds to the societal and political pressures to understand and mitigate the effects of climate and environmental change and forecast the impacts of these changes on the global population.

Data types used

Key datasets for the GSI3D modeling software include licensed digitally geo-rectified nationwide topographic maps, including historic versions, satellite imagery, aerial photography and digital elevation models. These are combined with data from BGS's borehole index and downhole logs, geological map linework that includes mass-movement, artificial, superficial and bedrock geology as individual themes together with shallow geophysical datasets such as Seismic Refraction, Electrical Resistance Tomography and Ground Penetrating Radar. The software enables all the available geoscience information to be assembled and visualized in a 3D workspace to construct the best possible geological block model.

It is essential that all these datasets are held in interoperable formats that can be exchanged between GSI3D and other modeling platforms and are stored in standard formats that will be recognizable to the next generation of software and modeling tools.

Building the 3D geological models of shallow subsurface with GSI3D

In simple terms, the GSI3D software utilizes a Digital Terrain Model as the model capping surface, plus geological surface linework (maps) and downhole borehole data to enable the geologist to construct regularly spaced intersecting cross sections by correlating boreholes and the outcrops-subcrops of units to produce a geological fence diagram of the area (Figure 1a-c). Mathematical interpolation between the nodes along the sections and the limits of the units (outcrop plus subcrop) produces a solid model comprised of a series of stacked triangulated objects corresponding to each of the geological units present (Figure 1d-e). Once calculated the block model can be analysed to solve problems as a decision support system (figure 1f-h).

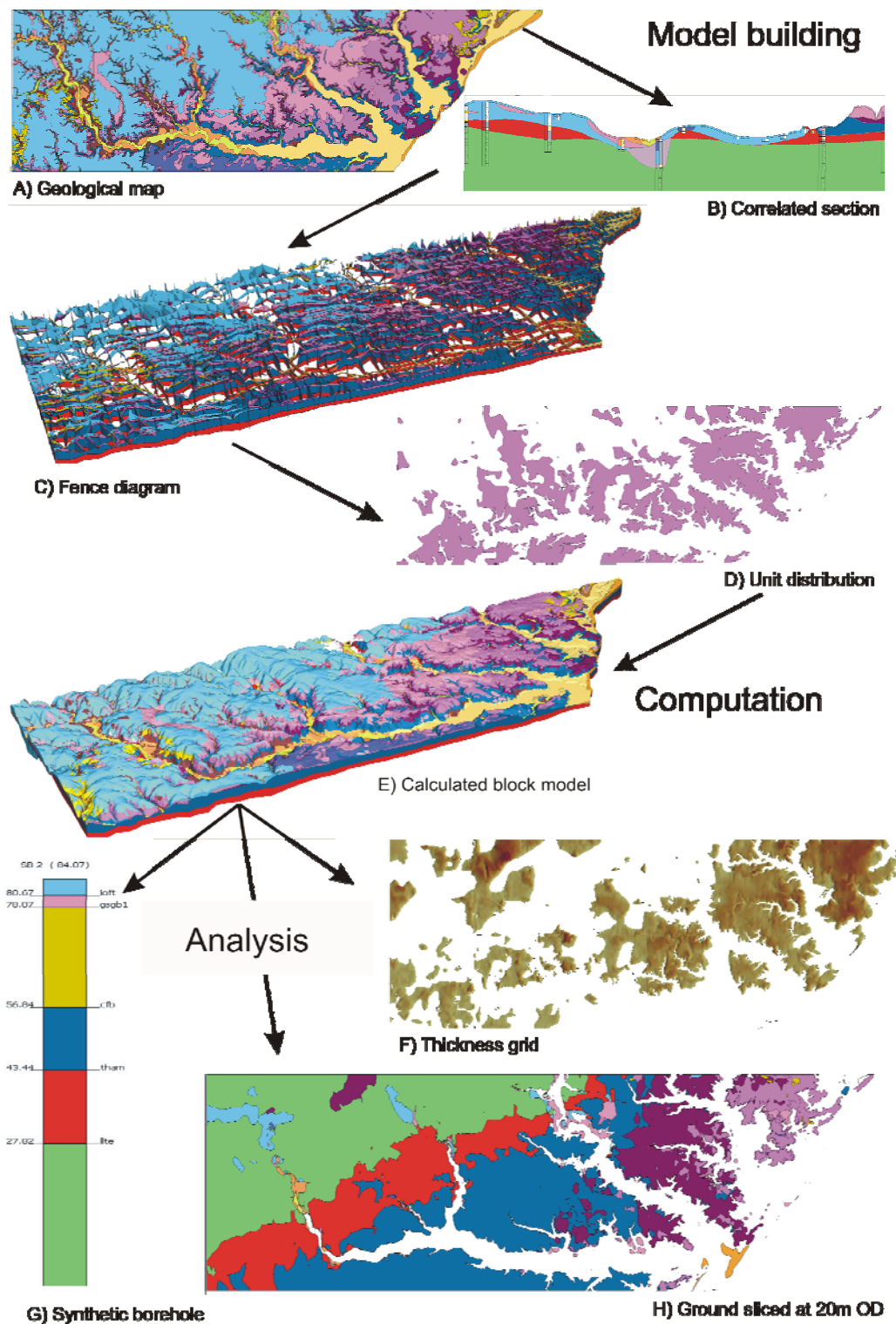


Figure 1 The GSI3D Modelling Workflow

This process is intuitive and easy for all to use because it simply performs in the digital environment the techniques that geologists have been performing since the start of the science. So the geologists determine the sequence of deposits, classify borehole logs, draw cross-sections and define the surface and sub-surface extent of each geological unit. Geologists make their decisions based on their wealth of understanding of the study area, geological processes, examination of exposures and theoretical knowledge gathered over a career in geology.

More details on the software and methodology can be found at:

<http://www.bgs.ac.uk/science/3dmodelling/gsi3d.html>

or <http://en.wikipedia.org/wiki/GSI3D>.

Methods of model delivery

Figure 2 summarizes current outputs from GSI3D modeling process. These include reports delivered on line as PDFs with embedded models as 3D PDF's. For users of GIS s standard outputs such as grids, TINs and shapes are also supplied. However most models are delivered using our stand-alone Sub-surface Viewer, or browser. This frees clients from the need to purchase software to analyse the models, all that is required is a modern PC or laptop with a high performance graphics card. The functionality of this Viewer includes uncovered geological maps, synthetic borehole prognoses synthetic cross-sections along specified routes, horizontal cuts of the ground at defined elevations, views of single geological objects, exploded views of the whole model and the ability to instantly switch the model schema between different properties or attributes. Commonly used attributes include geological name, age, genesis plus physical properties such as lithology, permeability, physical strength and mineral potential. Web delivery will become the standard way in which BGS disseminates all its geological models and component datasets in the near future.

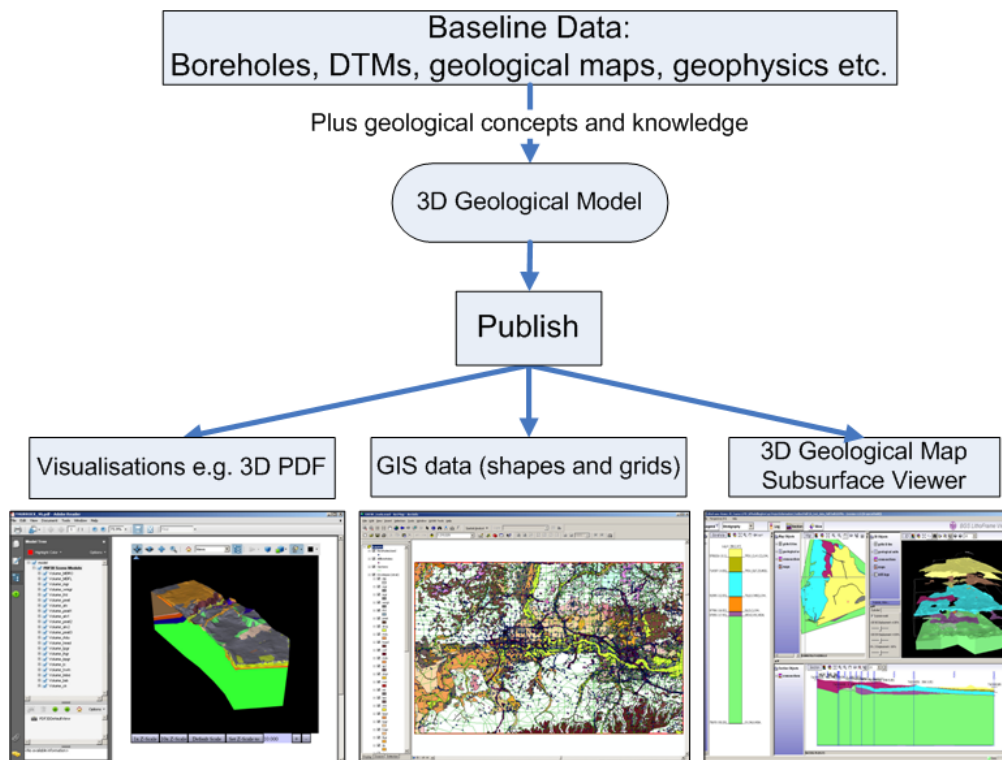


Figure 2 Mechanisms of delivery of Geological models

A small demonstration model of the Thurrock area of East London together with a brief manual on operation of the sub-surface viewer can be downloaded free from here <http://www.bgs.ac.uk/downloads/start.cfm?id=536>.

Usage of models

These 3D geological block models as delivered in the Sub-surface Viewer have a thousand and one potential uses and users. Here we briefly describe two examples

The example below shows how cookie-cuts from block models can be used in either the planning or maintenance of linear routes and infrastructure. Potential applications include major highways, rail networks, inland waterways, tunnels, pipelines and electricity grid routes.

In the case of planning several scenarios can be assessed to achieve a route most suitable from a geotechnical and engineering perspective. The model can be interrogated to derive cross-sections along a series of competing alignments or buffered as in the case below to produce a ribbon of geology encompassing a specified or existing route. By switching the model attributes evaluation of factors such as ground strength, potential groundwater flow pathways and aggregate resource sterilisation can be assessed. Groundwater levels can also be incorporated for visualisation in the model. Where no block model already exists the model can simply be constructed from all the existing geoscience information

at the planning stage. The models are also potentially useful in upgrading and repairing our existing infrastructure.

The example below, which is for illustration only, shows the ground conditions along a 100m wide corridor along the two major trunk roads that converge on Britain's main container port at Felixstowe Docks in East Anglia. This network is very heavily used and of considerable national economic importance. The model shows a variety of thin and complex superficial glacial deposits in blues and pinks that includes regionally important aggregate resources, these are cut by recent river and tidal deposits in yellow and brown that present major engineering challenges due to their unconsolidated nature. These superficial deposits rest on Palaeogene-Cretaceous bedrock dominated by the thick and Chalk Group in green that forms the principal aquifer of southeast England. The overall block model for this area has been used in hydrogeological modelling to assess factors such as recharge potential, groundwater resources and aquifer vulnerability.

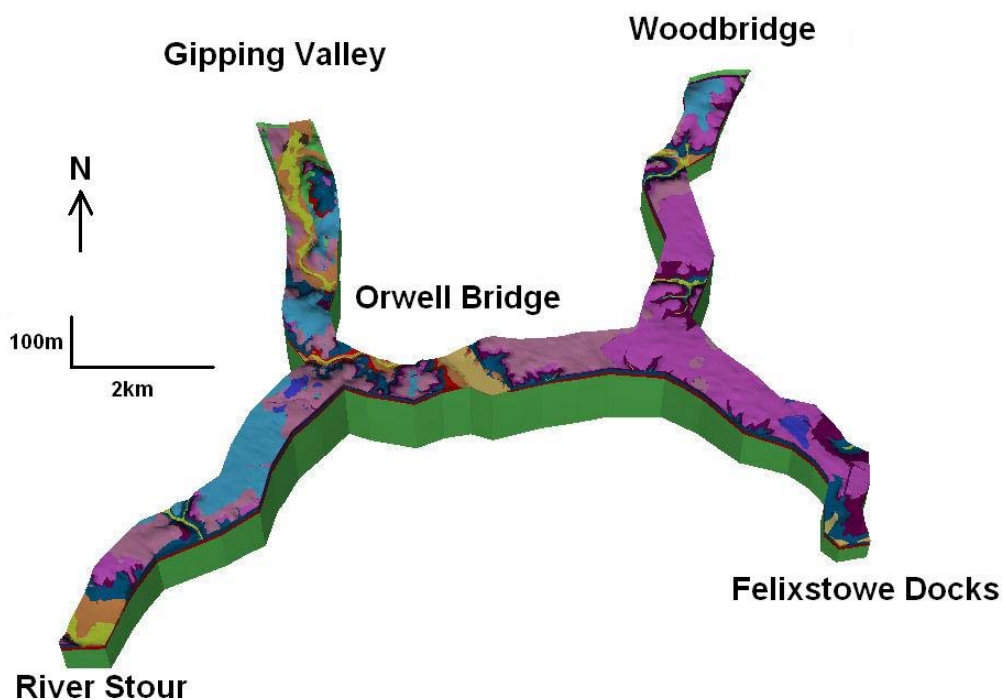


Figure 3. Cookie-cut block model along major highways leading to the Port of Felixstowe, UK

In the field of hydrogeology extensive modelling has occurred in Britain's two main aquifers the Cretaceous Chalk and the Triassic Sherwood Sandstone Group. Many of these models have been commissioned by the regional water companies or the regulatory Environment Agency of England and Wales. The models have been used to assess aquifer vulnerability, recharge potential, groundwater resources and abstraction impacts, and also to investigate groundwater flooding events (see Figure 4) and major industrial and agricultural aquifer contamination resulting from spills and leakages.

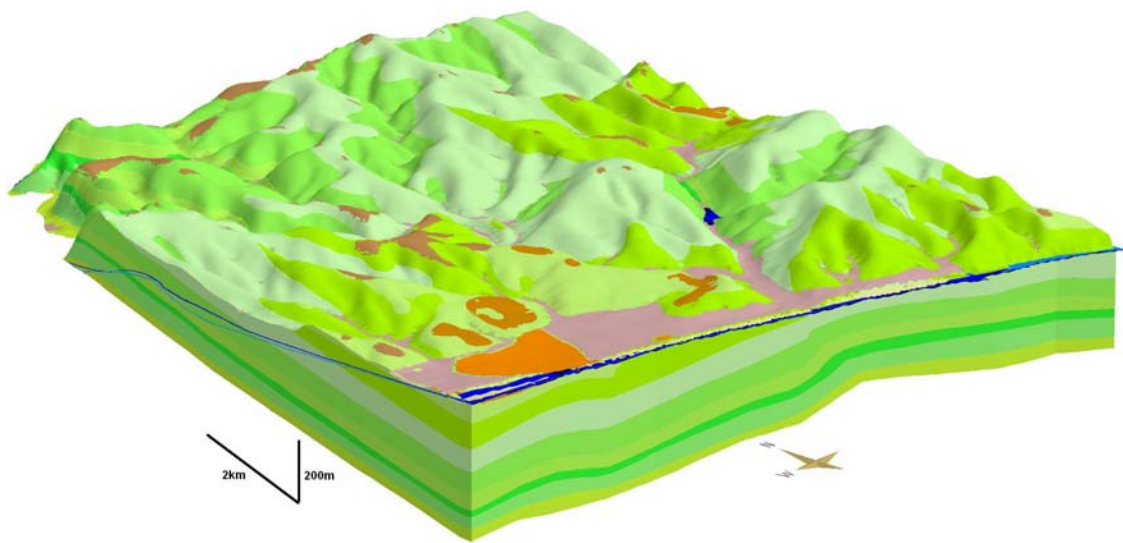


Figure 4 Detailed model of the layers of Chalk Aquifer (shades of green) in the Patcham area of the South Downs, England together with the ground watertable indicating areas at surface prone to groundwater flooding events (blue at surface). The orange and brown deposits are thin superficial deposits.

Other uses of block models include site-specific studies for new underground metro stations and other major infrastructure construction projects such as bridges, the 2012 Olympic site and nuclear power stations, the models are also used by some local planning authorities to help evaluate future development proposals.

Archaeological studies have also made use of the GSI3D technology in Cologne and London. An increasing use of models in several cities is to provide automated borehole prognoses for ground source heatpumps especially into the Chalk aquifer beneath London.

However the biggest beneficiaries of the migration from maps to models are likely to be in geological education and public understanding of science.

In education block models can be constructed of classic areas of geology and perhaps examined as a precursor and/or follow-up to a field visit. The ability to slice and dice a block model of somewhere they know having walked around the surface will considerably enhance understanding of geological structure and the visualisation capability of geology students. The integrated use with fly-through visualisation systems such as Geovisionary™ (<http://www.virtalis.com/content/view/371/618/>) will further enhance the experience and make virtual field trips and geological surveying reconnaissance possible. Similarly the development of simple demonstration models of structures such as the various types of unconformities, folds and faults that can be queried and dissected will lead to improved understanding of structure and geological concepts.

We also now have the tools to show the public at large what goes on beneath their feet and to help them understand political or planning decisions, or the resolution of disputes based on our evidence and understanding of the subsurface - the domain of the geologist.